Chapter Three

Cutting Simple Gears

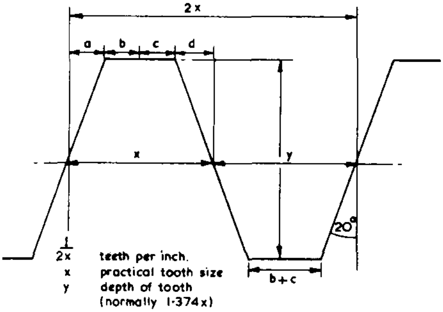
I make no apology for apparently repeating a chapter on gear cutting from my first book "Making the Most of the Unimat", but the chapter has been rewritten to cover better both the Unimat 3 and SL operations, and it has also been simplified. I have been told that even an expert model engineer would think twice about cutting his own gears, but I have had no difficulty using these methods which I developed. Those who have doubts can of course try to buy commercial gears to do the job. The chapter is repeated because most of the projects in this book require some sort of gear to be cut – square toothed for toothed belt drives for the machinery, and spur toothed for the small traction engine as well as a wormwheel and pinion for its steering gear.

INTRODUCTION

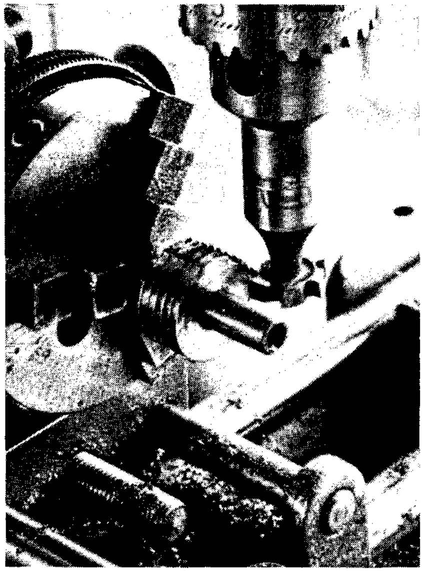
When a spur gearwheel is made to be run with another spur gearwheel the teeth should have a particular shape so that they will mesh together well, run together with the touching areas rolling rather than rubbing, one on the other, and present the maximum touching areas possible yet still escape easily. Straight teeth, hard in mesh, will lock together, and when the mesh is loosened, to enable the teeth to escape, the teeth rub along the length of the teeth on the other wheel, giving frictional loss of power. In practice a modulated straight-sided tooth form is used which has its upper half angled and made rounded. This tooth form is relatively easy to generate in straight-across spur gears with the correct form of cutter.

Among the items listed as accessories for both the Unimat 3 and the Unimat SL are gear-cutting mills, which are specially shaped side-milling wheels. These gear-milling cutters cut a gap, not a tooth, and leave the sides of the gap correctly made to form a gear tooth when the next gap is cut; the indexing attachment is used to position each cut correctly. This system limits the usefulness of each modular cutter to a certain size of tooth and to small variations in gearwheel diameter. Six of those cutting wheels are required to cover the range at a cost of over £100–plus the cost of the arbor!

A cheaper, and more extensive, method of cutting gears is to use the divisions provided by the indexing attachment, but with home-made tooth-cutting tools. The cutter takes the form of a multi-toothed hob, quite easily made on the Unimat lathe, which not only cuts a straight-sided gap into the gearwheel blank but simultaneously modifies the tooth shape being formed either side of the gap.



GEOMETRY OF THE CUTTER TEETH



Photograph at right shows the hob being grooved with a Woodruffe cutter.

This means that the cutting hob can be straight-sided with no fancy cutting pattern built in, it can deal with any diameter of blank, from large down to small, and a number of hobs can be made to give large or small tooth sizes which will run together well with other teeth of the same size which have been cut with the same hob. The hobs can be made on any other lathe, of course, and used on any milling and drilling assembly with an indexing unit.

The hobs are made from round silver steel turned on the lathe, then cutting teeth are formed using the indexing attachment and a grinding wheel in the vertical mode. Silver steel contains no silver and is quite inexpensive. It is steel which contains sufficient carbon to make it suitable for hardening and tempering, particularly for tool-making. It is produced in a range of sizes to very fine tolerances, and is easy to machine. The hardening and tempering part is not difficult and can be carried out using a small blowlamp or even just a gas-ring. Most tool merchants sell lengths of silver steel, as do many of the advertisers in the magazines.

THE HOBS

To avoid complications this system of spur gearcutting uses teeth per inch (t.p.i.) for measurements of gearwheels, which means that the old-fashioned Whitworth and BSF screw-threads can be brought in as a cutting guide when making hobs on the lathe. The disadvantage of using teeth per inch is that the gearwheels end up with odd sized diameters, due to π; however, the modern calculator can be brought into use to assist the drawing-up of tables. The

tables show the diameter of blank required for a particular number of teeth, and the working radius of the finished gearwheel for various tpi sizes, covering the range of indexing possibilites of the Unimats.

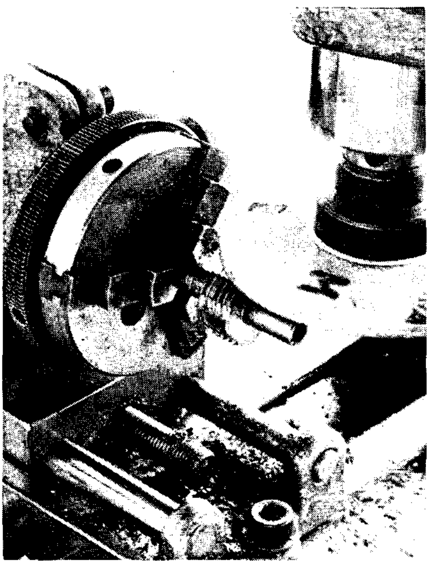
The geometry of the hob is shown in the diagram: x is a distance halfway down the tooth, if there are ten teeth to the inch then x= .05in. If a = b = c = d, then y = 1.374x; this gives a standard short tooth ; y can be increased to 1.5x to give a slightly longer tooth and allow the hob to wear and be sharpened. Figures for both are tabled to the equation:

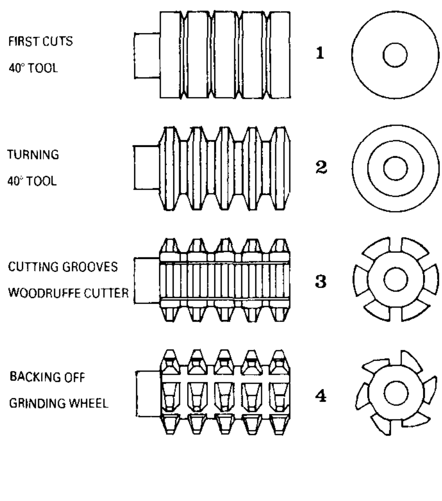
$$\frac{\text{number of teeth required}}{\text{teeth per inch} \times \pi} + (2 \times \tfrac{1}{2}y) = \text{diameter of blank}$$

The length of the bottom of the groove between the teeth when y = 1.374x is b + c ½x, but when y = 1.5x the bottom of the groove becomes .454x. The hobs have a central cutter, cutting a space, with two cutters either side modifying the forming teeth either side, mainly above x, dependent on the curve of the blank. If a tooth were to be cut instead of a space the outer edges of the two cutters would not be radial and would cut under the x line and produce a hollow tooth, and the form of tooth cut would vary considerably from large to small gears.

The four hobs which I made correspond to 1in., ¾ in., and ½ in. Whitworth, and to ½ in. BSF. These give selection of eight, ten, twelve and sixteen teeth per inch. The hobs are made from ¾ in. diameter silver steel, bored ¼ in. and secured to a ¼ in. axle for both making and using them, with a 4 BA Allen grub screw. A lathe tool is required to cut the 40 deg. angle (20 deg. either side), and

Backing off the cutter teeth.





Stages in Making Hobs

No of Teeth	Diameter of Blank								½ x D.P. of Gear Wheel			
	y = 1.374x				y = 1.5x							
5	.238	.228	.19	.143	.293	.234	.195	.147	.1	.08	.066	.05
6	.325	.26	.217	.163	.333	.266	.222	.167	.12	.096	.08	.06
8	.405	.323	.27	.202	.412	.33	.275	.206	.16	.138	.106	.08
9	.444	.335	.296	.222	.452	.362	.301	.226	.18	.145	.119	.09
10	.484	.387	.323	.242	.492	.394	.328	.246	.199	.16	.133	.1
12	.564	.45	.376	.282	.572	.457	.381	.286	.239	.19	.159	.12
15	.683	.546	.455	.342	.69	.553	.46	.346	.299	.24	.199	.15
16	.723	.578	.48	.362	.73	.585	.487	.366	.319	.255	.212	.16
18	.80	.642	.535	.401	.81	.648	.54	.405	.358	.286	.239	.18
20	.882	.705	.588	.441	.89	.712	.593	.445	.398	.318	.265	.199
24	1.04	.833	.694	.52	1.05	.839	.70	.525	.478	.382	.318	.24
30	1.28	1.02	.853	.64	1.29	1.03	.859	.644	.597	.477	.398	.299
36	1.52	1.21	1.02	.76	1.53	1.22	1.02	.763	.716	.573	.478	.36
40	1.68	1.35	1.12	.84	1.69	1.35	1.13	.843	.796	.636	.53	.398
48	2.0	1.6	1.33	1.0	2.01	1.6	1.34	1.0	.955	.764	.636	.477
60	2.47	1.98	1.65	1.24	2.40	1.99	1.66	1.24	1.19	.955	.795	.596
72	2.95	2.36	1.97	1.48	2.96	2.37	1.98	1.48	1.43	1.15	.955	.716
80	3.27	2.62	2.18	1.64	3.28	2.62	2.19	1.64	1.59	1.27	1.06	.795
96	3.9	3.13	2.6	1.95	3.92	3.13	2.69	1.96	1.9	1.53	1.27	.955
	8	10	12	16	8	10	12	16	8	10	12	16

Teeth per inch

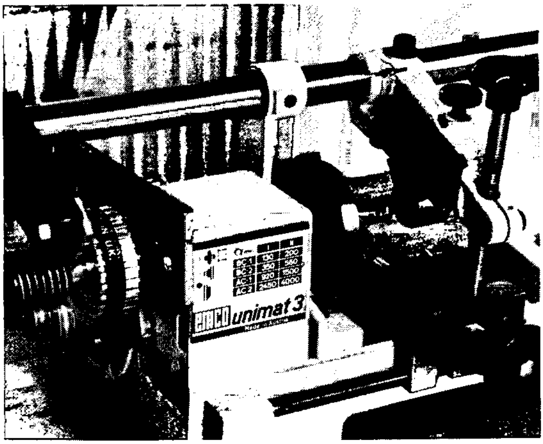
this is best made from a ¼ in. square HSS tool blank, using a grinding wheel, and a protractor set to the required angle. The tool should have an angle of 40 deg. between its two faces, which are backed off on the downward direction. The top surface is relieved back and to the left; the tool is pointed but the cut made flat-bottomed. When used the tool is fed in to match the left side of the cut, advanced, and a further cut made.

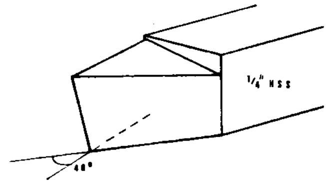
Other tools needed for making the hobs are a ⅛ in. x ½ in. Woodruffe cutter for the grooving, and a disc grinding wheel for backing off the cutting teeth of the hobs. You will also require a simple depth gauge, which I will describe later.

MAKING THE HOBS

First cut a length of silver steel, five times the overall tooth size plus ⅛ in. for the Allen grub screw, so for the eight teeth per inch hob cut a ¾ in. length. Face both ends in the three-jaw chuck, drill with a No. 3 centre drill as far as the flutes allow and then drill right through with a ¼ in. drill. Drill No. 32 for the grub screw and tap 4 BA. Run a ¼ in. reamer through the bore, fit a ⅛ in. long 4 BA grub screw and secure the blank to a piece of ¼ in. silver steel rod for turning between centres.

Take a light cut from the surface to ensure concentricity, then turn the securing screw end down below tooth level. With the 40 deg. tool make four shallow cuts between the teeth. To measure these the handwheel divisions can be used, fifty divisions equalling ¹⁄₁₀ in., but check with a rule before continuing; keep the appropriate BSF or Whitworth bolt handy as a quick check whilst working. Cut the two grooves, from left to right, either side of the central tooth, to the correct depth, using the geometry as explained, and a depth gauge. The width of the bottom of the cut can be regulated with the handwheel





LATHE TOOL FOR MAKING HOBS

Photograph on left shows the set-up for cutting a wormwheel.

divisions. Cut the other two grooves to form the five matching teeth, and finish by cutting the two outer surfaces to a 20 deg. angle.

To make the teeth into cutters set the work on the 1/4 in. mandrel in the three-jaw chuck, on the indexing head with the 36 division wheel in place, and lock the head onto the cross-slide. Use the Woodruffe cutter to make six slots across the grooves, at six division intervals, taking the slots down to just below the teeth. But feed in no more than five or six handwheel divisions at a time before running the cross-slide across; a greater feed causes overheating and soon blunts the cutter. Replace the Woodruffe cutter with a disc grinding wheel, set the dividing head three teeth back and grind off about two-thirds of tooth area. Set the head two more teeth back and back off finely almost to the cutting edge, all six slots. Clean off all traces of grinding from the lathe, dismantling if necessary.

HARDENING AND TEMPERING

Remove the set screw and push the hob on to a piece of copper pipe, 3/8 in. O.D., whose end has been cut and squeezed together, and place on a hearth. Have a pair of old pliers and a can of cold water handy. With the blowtorch heat up the hob to cherry red, pick up the copper pipe with the pliers, keeping the pipe upright with the hob at the top, and give a final blow to ensure redness, then dunk it in water. Include the copper pipe in the dunking or you will get a surprise when you pick it up again. Take the hob from the water and replace the water with cold. With a good file vigorously attack the flat bottomed grooves, where it should do little but remove a little blackening. With emery cloth clean the ends, including the extra surface for the set screw, and push the other end back onto the copper pipe to reheat. This time hold the pipe with the pliers and heat the copper, only, until the cleaned parts of the hob go to a nice yellow, as if the hob has been varnished, and then dunk in the water. The hob is

now finished, there is no need to clean off, and you will have burnt off the burrs with the first blow.

MAKING GEARWHEELS

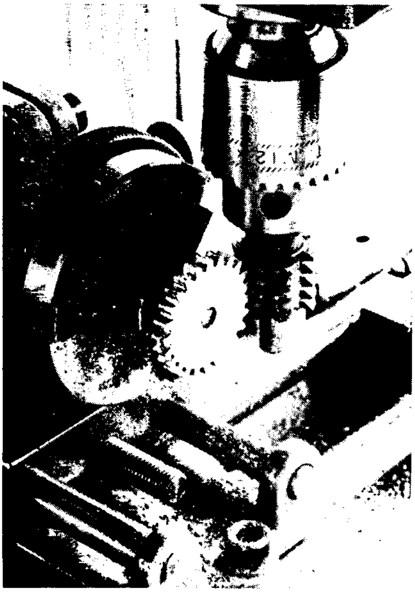
To make a gearwheel first cut the blank with a diameter a little larger than the finished diameter. Use the table to find the size of blank needed for the size and number of teeth. The effective radius of the gear is given in the last part of the table; this is the radius which can be used to draw a circle touching another circle to represent two gears in mesh without worrying about the teeth. It can be used for positioning the centres of gearwheels to be run together.

Take the blank and rub down one side flat on emery cloth on a flat surface, to remove sawcuts. Chuck the blank, finished side in, in the three-jaw and turn to a finish as much of the surface as the jaws will allow; enough of the centre of the blank needs finishing to take the mandrel, and the rest can be finished on the mandrel.

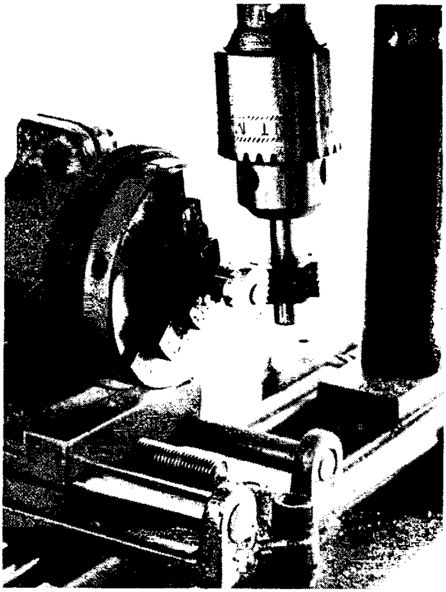
Centre-drill right through, following with a drill the diameter of the mandrel. Fit the blank to the mandrel and secure to finish the front surface and to turn down the diameter to the blank sizes, checking with a vernier caliper.

Select the correct dividing wheel for the indexing attachment; the Unimats have four sizes of dividing wheel, 30, 36, 40 and 48 teeth for the S.L., and 24, 30,

Cutting a gear with the hob.



Cutting angled teeth on a pinion.



36 and 40 divisions for the Unimat 3; the table shows the possibilities with these plates up to 96 teeth. Using this hob method to cut, say, sixty teeth with the 30 dividing wheel, you will find after cutting the spaced thirty teeth that the intermediate teeth are almost finished and require the minimum of cutting. With the indexing attachment on the cross-slide secure the blank, on the mandrel, in the chuck, and have the hob driven in the drill chuck on the vertical head. Bring the cross-slide right over, forward, and the vertical head down the column until the hob presents its middle cutting row to the horizontal centre of the blank; finalize by adjusting the quill, using the vertical fine-feed attachment if you have it. Turn the handwheel until the hob can cut into the blank, and cut through by means of the cross-slide movement. Smaller teeth sizes can be made with a single pass, forward and back, then turning for the next indexed cut; lock up while cutting. Larger teeth, and teeth in harder material, will need more than one depth of cut, in which case note the longitudinal slide handwheel setting for each cut and for the final position cut and write them down, as you may be interrupted halfway through the job. Remove the completed gear from the mandrel and rub off burrs on emery cloth.

LIFE OF THE HOB

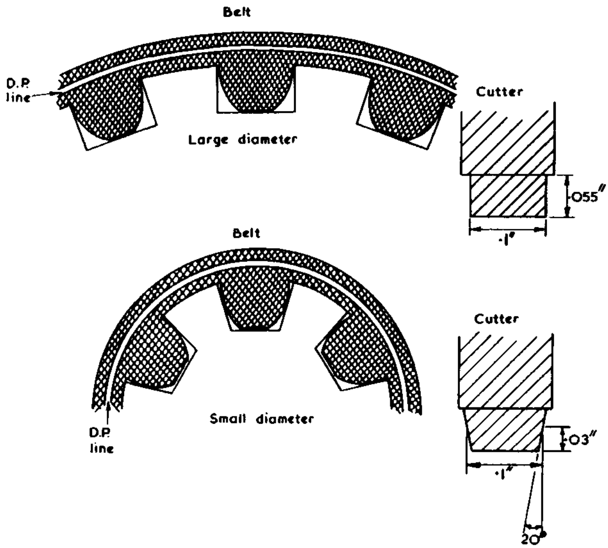
So far I have only used my hobs for cutting gearwheels in aluminium alloys and brass and the cutters show no signs of blunting. To sharpen the hobs the leading cutting edges would need a light stoning by hand, then the hobs should be turned at speed and a flat stone run lightly against the top of the teeth. There is no reason why the cutters should not be used to cut teeth in mild steel blanks, but care must be taken to avoid overheating by using less of a cut, also the hobs will need more attention by sharpening.

TOOTHED BELT DRIVES.

Toothed belt drive systems provide the same positive drive as gears in mesh, but with the flexibility of positioning that a pulley and belt system provides. A toothed belt drive is more like a chain drive, as it cannot slip, yet unlike the chain drive it requires no lubrication, and is quiet.

The toothed belt is usually from a synthetic rubber, for the belt and teeth, which are reinforced and moulded around non- stretch nylon cords within the continuous part of the belt. The nylon cords become the part about which the belt flexes, and they thus determine the pitch of the belt and teeth around wheels, and the positioning of the teeth. There is little or no information available for the model engineer wishing to make toothed wheels to run with the belts (the manufacturers of the belts supply wheels to run with them) and so I devised my own cutters to make the wheels.

I have been making and using these square-toothed wheels for over two years, to run with just one size of belt. During this time I have been using the drive system for my Unimats and for various workshop machinery I have made all with far more positive drive than previously.



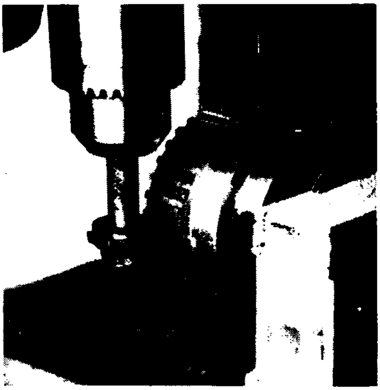
The size of the toothed belt is 100 x LO31, which is a lightweight belt with five teeth to the inch, each tooth being one tenth of an inch long with the same size space alongside. The teeth are one twentieth of an inch high, formed approximately as in the diagram. They can be readily obtained from model shops where they are a spare for a radio controlled stock car.

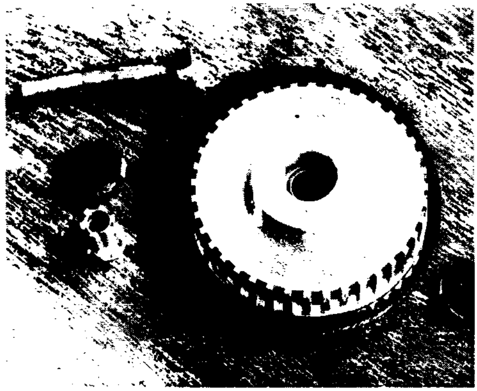
When the belt is manipulated it can be seen that while the teeth remain quite stable the size and shape of the spaces can be made to vary quite a lot; with diminishing diameter the gaps compress but the teeth do not. This can be seen in the diagram. Cutters for making toothed drive gearwheel are made to cut a single space between teeth, only, as that is the correct and finished shape. The cutter for larger diameter wheels has straight side, but the one for smaller wheels has to have angled sides to cut away rather more of the tooth side and so allow for the compression of the belt spaces.

To make a gearwheel the size of the blank is calculated to accommodate multiples of one tooth plus a space, around the circumference, and although the non-stretch nylon cords will cause a need for small reduction of the straightforward diameter, in practice the effect can be ignored unless the belt is to be run without much tension, in which case the after-treatment of a few thou. turned off the toothed wheel will do the trick. The formula for the diameter of the blank is:

$$\text{Diameter of blank} = \frac{\text{Number of teeth required}}{5 \times \pi}$$

The cutters are made from 1/4 in. thick slices of 3/4 in diameter silver steel, with a 1/4 in. bore, and they are turned, grooved and ground into cutters on a


Forming square teeth.

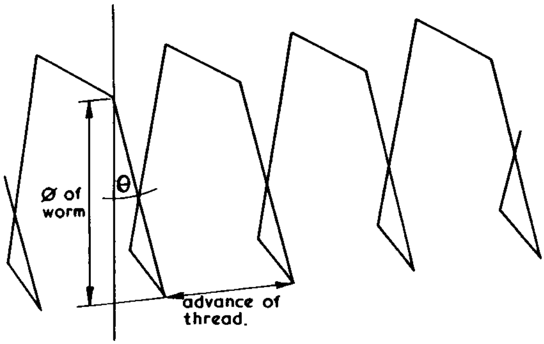

A toothed drive shown with the cutters.

mandrel made from 3/8 in. diameter mild steel, turned down to a 1/4 in. diameter collar, 3/16 in. long to take the cutters. To harden and temper the cutters, use the copper as before. The work is carried out in the same way as for the hobs, and the cutters are then used to cut the blanks with exactly the same methods.

When the gearwheels have been cut from the blanks check their accuracy with a toothed belt held tightly in place, having removed any burrs beforehand by running emery cloth against the turning gearwheel. Position the gears and belt so that the tension applied gives no more than a deviation of 1/8 in. on a straight 2in. stretch of belt . When running a toothed belt system it is usually necessary to contain the belt in some way to stop the belt running off. With a small gear driving a larger gear by means of a toothed belt it is sufficient to rim the smaller gear; this can be by means of two co-axial flanges secured either side of the cut gear.

WORMWHEELS AND PINIONS.

Whilst I was devising a way to fit non-standard threading leaders to the threading attachment I found a way to make multiple-start worm-wheels on the Unimat SL. I had made the leader from a 1in. Whitworth bolt by sawing off the head, drilling through 1/4 in., fitting an Allen grub-screw and securing it co-axially with a length of drilled brass rod on a silver steel rod centred in the lathe. The follower of the bolt's thread was a piece of 1/8 in. brass plate, filed on one side. After cutting one lot of coarse thread on the brass it became immediately obvious that, by simply turning the bolt relatively through 180 deg. a two-start worm would result, keeping the bolt hard against the chuck jaws both times. By using the angles of the chuck jaws as a guide a three-start worm could also be made. The same methods can be used with the Unimat 3, giving the modified bolt leader a 6mm hole, fitting it in the standard, outside, position on the threading set-up. The pulley against which it seats could be calibrated for the various starts.



SIMPLIFIED WORM GEOMETRY FOR CUTTING PINION

Since the 1in. Whitworth bolt has eight threads per inch the two-start worm becomes sixteen per inch, and a pinion of sixteen teeth per inch is needed to run with it. For this I used the cutter of ¾ in. diameter, which I had made with the other hobs. In theory the cutter should be of similar diameter to the worm-wheel so that the pinion embraces the wheel. However, as the pinion was to be comparatively thin the ¾ in. hob proved satisfactory.

To enable the pinion to run at 90 deg. to the worm the teeth have to be cut at an angle. When viewed from the side a worm- wheel presents a complexity of angles, and with a pinion whose thickness in under half the diameter of the worm it is the angle at the centre of the worm's thread which must be considered. To determine this angle it is simplest to imagine the worm as square in section, then each side of the square will advance by one quarter of the complete advance of the start. It can then be seen the angle of the teeth of a pinion to mesh with that particular diameter of worm be found from:

$$\tan\theta = \frac{.25 \times \text{thread advance}}{\text{diameter of worm}}$$

This calculation gives a compromise angle, close to the lead angle, which runs very well in practice, giving a good tight fit with no backlash. So with a worm of outside diameter ⅜ in. cut to 8 t.p.i. (the number of starts is not involved) the thread advance is ⅛ in. and a quarter of this is 1/32 in.; .03125 over .375 equals .083R: this is tan. theta. On the calculator this represents an angle of 4.75 deg., the angle to cut the teeth.

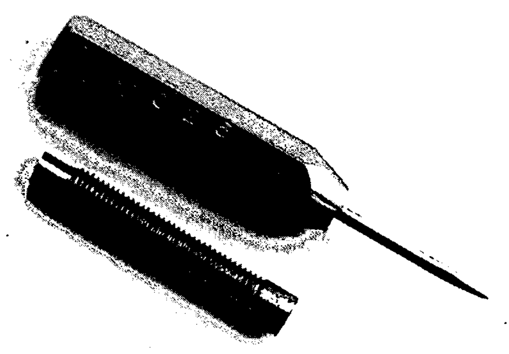
To cut the teeth of a pinion, set up the blank as before, but this time bring the centre line of the vertical head to correspond with the lathe centre line. Turn the vertical head the correct deviation from the upright, ensuring the angle is correct using the flat side of a rectangular protractor from the cross-slide. Bring the blank across and check against the worm-wheel that the angle is in the right direction, and not cutting incorrectly by a further x degrees. Cut the worm by feeding the blank on to the cutting hob; do not cut across but make the pinion hollow for the worm-wheel. The worm-wheel, by the way, should have been cut with the 40 deg. tool that you made for the hobs.

A SIMPLE DEPTH GAUGE.

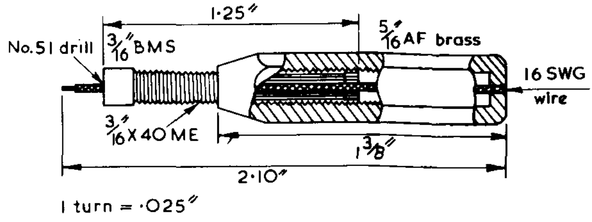
When making hobs and cutters for gearwheels, and when cutting gears, it helps to have a depth gauge on hand for getting the depth of the grooves just right. A simple but accurate depth gauge can be made by relying on the 40 t.p.i. Model Engineer series of taps and dies; either 3/16 in. or 1/4 in. can be used. The 40 threads per inch give a movement of .025in. to each complete turn on the gauge, and by using the faces of a hexagon then 4 thou. is measured as near as you will want. The one I made was with the 3/16 in. x 40, but for the 1/4in. x 40 one, just use a larger size of hexagon brass and 1/4in mild steel rod.

Take a 1 1/2 in. length of 5/16 in. A.F. hex. brass and chuck in the three-jaw. Turn both ends to finish down to 1 3/8 in., and with a No. 1 centre drill, drill into one end as far as the flutes will allow, follow this with a No. 51 drill right through, then drill No. 21 to a depth of 1 1/4 in. With the 3/16 in. x 40 second tap in the drill chuck mounted in the tailstock, tap as far as you can, loosening the quill of the SL for advancement, or adjusting the tailstock position for the 3. Remove the tap and the swarf, to tap again with the plug. Turn a taper on the hexagon until only a thin face of metal remains, to the thread. Reverse and take off the back corners.

Face the ends of a length of 3/16 in. diameter silver steel or BMS and turn the end 1/8 in. down to .09in., centre drill the end, then drill in 1 5/16 in. with a No. 51 drill. Get 1 1/4 in. protruding from the chuck, and with the 3/16 in x 40 die in the tailstock dieholder, thread 1in. past the turned-down end, first with the die wide open, and then again with the die not quite relaxed; use plenty of tapping compound to get a nice clean-cut thread. Try the hexagon on, and it should screw quite tightly with the fingers. Put a pointed lathe tool in the tool holder on the cross-slide, bring the point up to the thread and, by turning the bed-



The simple depth gauge shown dismantled.



DEPTH GAUGE

slide handwheel, score a fine line through the threads. Remove and mark off the 1¼ in. and wrap a ¾ in. wide strip of alloy around the threads and chuck in the drill chuck. Part off the 1¾ in., and face off the anvil. Push a No. 51 drill through the bore to clean away the burrs, then screw about ⅜ in. into the hexagon brass. Take a length of 16 s.w.g. steel wire (use the stuff that the model shops sell as piano wire in straight 3ft. lengths but take a vernier caliper with you to check the gauge) and grind the end to a tapered point and blunt the point straight across.

Push the blunt end into the gauge to protrude at the anvil. If all is well remove the wire and clean off to tin with Comsol at the 2in. to 2.1in position, rub the solder down flush. Smear the hole in the hexagon brass with Comsol paste, and push in the wire to the 2.1in. Solder in the wire with a small flame or large soldering iron, touching the joint with Comsol wire to consolidate. Allow the joint to set and cool naturally, and with a small hacksaw cut off the surplus wire, place in the vice and flush with a fine flat file. Remove the threaded part and clean both parts. Smear the threads with grease and screw right home, unscrew and take off the surplus lubricant.

To zero the gauge rest the anvil on a dead flat surface and hold it upright and still, turn the hexagon slowly, and the needle will lift the anvil from the surface as the zero point is passed, back off the hex. until the needle coincides, level, with the anvil, and, mark the position of the line cut into the threads onto the taper of the brass. To finish off stamp .025 on the brass, on the opposite side to the line, to remind you. To protect the little gauge beg one of the small tubular boxes that hold small twist drills from your tool merchant; it will accommodate the gauge neatly.

Remember that each complete turn of the gauge equals .025in., and in use complete turns need to be counted to get correct length of needle protruding from the anvil, or can be counted back from where the anvil has lifted on measuring the depth of a tooth cut.